

RADIATION AND TEMPERATURE OF THE SUN

551.52 : 523.7

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OSCILLATIONS OF THE SOLAR CONSTANT¹

General statement.—When we now take under consideration the question of the oscillations of solar radiation it can be, from the astronomical point of view, only a matter of investigating the changes in radiation that have their origin in the sun. There is, therefore, in the first place a question whether all disturbing influences are thoroughly eliminated in the observational material at the present time. In so far as this is not the case such oscillations in solar radiation afford occasion for a series of interesting meteorological phenomena, upon which we naturally can not enter in this manual.

Apart from rather short series of observations from Potsdam, Davos, Helwan, Warsaw, Upsala, and Pavlovsk, almost all of the available data are due to the work of the Smithsonian Institution. Through this unusual circumstance it results that in a statement of the problem there appear on one side a great number of writers who raise objections to the reality of the oscillations, and to whom there is opposed only one defender. Despite this there will be an attempt to give an objective survey of the present status of the problem.

considerable advance in refinement of methods of observation.

In considering the observed oscillation of the solar constant a differentiation must be made between those longer periods, which manifest themselves in the march of the yearly and monthly means, and those of a short-period nature, which show oscillations in the results of measurements within the course of a few days.

The observational data are, indeed, still too scant for a decision as to yearly oscillations. The long series of measurements from 1905 to 1920 on Mount Wilson could be undertaken only during the summer months. Observations throughout the year began at Calama in 1918 and at Harqua Hala in 1920, and their provisional results are now available to include the year 1924. Relative to the yearly march of these measurements it is generally assumed that:

1. The yearly means of the solar constant show a march with sun spot frequency in the sense that the higher solar constant values are observed in the years of increased solar activity. The degree of the relation for the years 1905 to 1917 can be represented by the following correlation:⁵

$$r = +0.627 \pm 0.124$$

2. In the year 1922 the yearly means of the solar constant show a noteworthy decrease (manifest also in the monthly means in fig. 13); the newly obtained value is maintained even up to 1924. Relative to the reality of this decrease there is argument in a recent investigation by C. G. Abbot,⁶ following which a change in reduction scale did not take place.⁷

Many have expressed doubt as to this. T. L. Eckersley⁸ in 1914, and soon thereafter H. Knox-Shaw,⁹ mainly on the basis of observations at Helwan, expressed the suspicion of a relation between the derived solar constant values and the transmission coefficients. As the cause there is pointed out the changing transparency of the air during the individual series of bolometric readings as is especially perceptible in the morning hours. Such variations were observed by G. Muller and E. Kron;¹⁰ also by A. Bemporad.¹¹ Similar objections to the authenticity of solar constant variations have been raised by F. Biscoe,¹² N. N. Kalatin,¹³ and E. Stenz.¹⁴ G. Granquist¹⁵ gave special attention to this question and disclosed especially for the Mount Wilson values for 1905–1908 and 1909–1911 a relation between solar constant and transmission coefficient. In 1924, W. E. Bernheimer¹⁶ investigated all of the Mount Wilson data, especially the monthly means from 1905 to 1920,

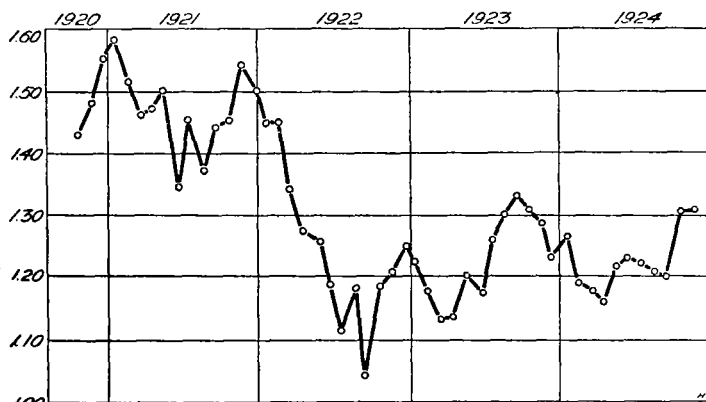


FIGURE 13.—March of the monthly means of the solar constant from October, 1920, to November, 1924. (Mean values from Montezuma and Harqua Hala)

Long-period oscillations. Yearly and monthly means.—The first statements which express a suspicion of a change in solar radiation, based on a rather long series of observation, originated in the year 1903. L. Gorczynski² demonstrated for the Warsaw observations a decrease in solar radiation from May, 1902, to the end of the year 1903, in agreement with the results reached by Ch. Dufour³ in Switzerland. According to S. P. Langley⁴ the decrease in radiation at the end of March, 1903, amounted to 10 per cent of the previous value.

If we now follow up the values of the solar constant that were obtained in America, first by Langley and later by Abbot, it appears without doubt that the amplitude of the long-period oscillation decreases materially in the course of the years, with the exception of the year 1912 in which the anomaly is due to the eruption of Katmai. During the same time there was success in attaining

¹ The original numbering of the figures is followed.

² *Strahlung und Temperatur der Sonne. Handbuch der Astrophysik. Band IV. Berlin, 1929.*

³ *Comptes Rendus.* 138. (1904.) p. 255.

⁴ *Comptes Rendus.* 136. (1903.) p. 712.

⁵ *Astrophysical Journal.* 19. (1904.) p. 305.

⁶ A. Angström, *Geografiska Annaler.* 1921. p. 162. See also W. E. Bernheimer, *Seeliger-Festschrift.* 1924.

⁷ *Gerlands Beiträge.* 16. (1927.) p. 344.

⁸ NOTE.—See C. G. Abbot. A group of Solar Changes. Smithsonian Miscellaneous Collections. Vol. 80. No. 2. (1927.) On page 6, Table 2 gives corrections to apply to solar constant values to bring them to the Mount Wilson scale of 1905–1920. From Jan. 1, 1923, to Jan. 1, 1921, it varied between +0.020 and +0.010; and between Feb. 1, 1921, and Apr. 30, 1925, between −0.002 and +0.008.

⁹ Helwan Observatory. Bulletin No. 14. 1914.

¹⁰ Helwan Observatory. Bulletins Nos. 17 (1915), 23 (1921), and 30 (1924).

¹¹ Potsdam (Astrophysikalisches Observatorium) Publikationen, 22. Nr. 64. 1912.

¹² *Memorie della Societa degli Spettroscopisti Italiani.* 6. 1921.

¹³ *Astrophysical Journal.* 46. (1917.) p. 355.

¹⁴ *Nachrichten des physikalischen Hauptobservatoriums.* Petrograd. I. Nr. 2. 1920.

¹⁵ *Circulaires.* Observatoire de Cracovie. 15. 1923.

¹⁶ *Meddelanden fran Venskapsakademiens Nobelinstitut.* 5. Nr. 1919, and *Kosmos Fysiska Uppsatser, Svenska Fysiker-Samfundet.* Stockholm. 1921.

¹⁷ *Seeliger Festschrift.* 1924. p. 452.

and was able to show that for the entire period such a relation is to be demonstrated. This relation is reproduced in Figure 14.

Later investigations by C. G. Abbot¹⁷ seek to establish the usefulness of the Mount Wilson values, but they reveal, meanwhile, that the measure of the oscillation observed there is reduced to half value. These results obtained by Abbot are represented in Figure 15. In similar manner the latest, as yet unpublished, monthly means for Montezuma have been evaluated. We shall return later to the new process of "Selected Pyrheliometry" introduced for application in this evaluation.

The state of affairs becomes considerably complicated in that not only do there result relations between the monthly means of the solar constant and the transmission coefficients, but, according to the investigations of C. F. Marvin,¹⁸ there straightway appears in the monthly means a regular march that can be referred only to atmospheric influences.

The data from Mount Wilson used in Figure 14 (exception being made of those for the years 1912 and 1913 in order to avoid the unusual disturbance due to the Katmai eruption) are those treated by Marvin. He arranges the

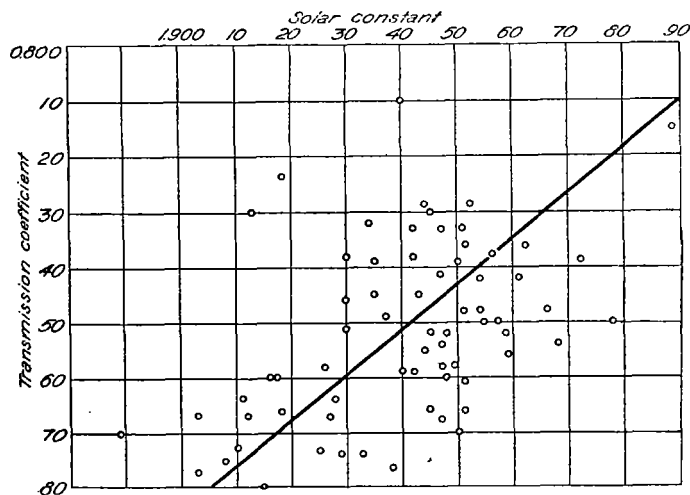


FIGURE 14.—The relation between monthly means of the solar constant and the synchronous transmission coefficients observed on Mount Wilson in the period 1905-1920 (after Bernheimer)

monthly means of all years continuously and plainly finds a period in the solar constant depending on the season. Singularly, the so-called definitive values of the solar constant show, after the application of the water vapor correction, the yearly march as still more pronounced.

This unexpected result would argue that the water vapor correction is not only insufficient, but even influences in an unfavorable sense the radiation values obtained after extrapolation. For the explanation of this special question still more exhaustive investigations must be set on foot. Also in the holographic measurements at Calama from 1918 to 1920 there appears a dependence of the solar constant on the season of the year; this is indicated, however, only in a moderate measure. This series can, therefore, be looked upon as the best and least distorted. In later years the effect enters again in full force, just as on Mount Wilson. Here it is a question of the monthly means from pyranometric measurements at Calama and Montezuma from 1919 to 1924, repre-

sented in Figure 16. This is all the more remarkable since these results are based on observations according to the so-called "Short Method," a method that in and of itself should lead to increased accuracy.

As is seen from Figure 16, Marvin could easily represent the march of the monthly means by a sine curve. The clearly defined seasonal effect is manifested in that the monthly means of the solar constant were observed to be higher in the summer condition (September to February) and lower in the winter condition (March to August) of the atmosphere.

Relative to the monthly oscillations of the solar constant a summarization may be made to-day about as

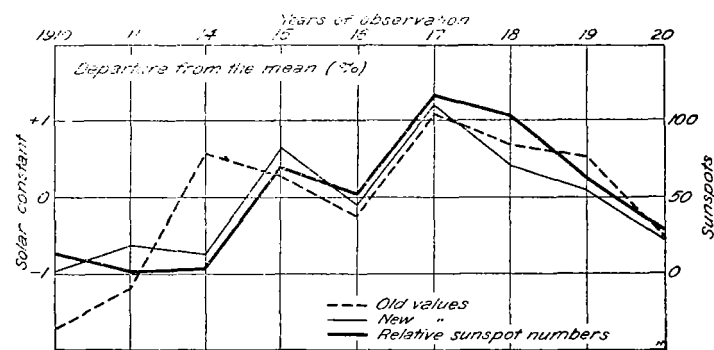


FIGURE 15.—July observations on Mount Wilson in the period 1910-1920. Observed oscillations of the solar constant according to the old method and results according to the new process of "Selected Pyrheliometry" compared with sun-spot frequency (after Abbot)

follows: A number of writers have demonstrated a dependence of the monthly means of the solar constant on transmission coefficients, thus on the condition of the atmosphere at the time. These observations are confirmed by Marvin, who discloses the meteorological cause of this dependence. This fact, however, gives no explanation for the entrance of errors into the extrapolation. So far it is only known that in the holographic determinations on Mount Wilson careful consideration of water vapor absorption intensifies the inaccuracy of the extrapolation. Then the pyranometric measurements (in which, as is shown later, changes in the condition of the air during a day probably no longer produce

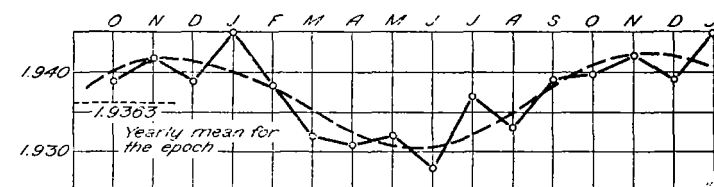


FIGURE 16.—Monthly means of the solar constant from observations on 1,030 days from July, 1919, to July, 1924. (Pyranometric measurements at Calama and Montezuma)

disturbing influences on the solar constant) show unequivocally relations to the atmospheric processes. Pyranometric values were used exclusively, however, in Figure 16.

On the other hand it must be emphasized that changes in the solar constant come to light plainly from year to year. (See, for example, fig. 13.) These changes must naturally be smoothed out in Marvin's method of forming monthly means for a group of years. Although, after consistent verifications, the monthly means of the constant, in so far as they have been published, can by no means be viewed as true values of extraterrestrial radiation, yet, doubtless, if the elimination of the influence of the earth's atmosphere should be attained, there may be

¹⁷ Popular Astronomy. 34. (1926.) p. 574. MONTHLY WEATHER REVIEW. May, 1926.

¹⁸ MONTHLY WEATHER REVIEW. 53. No. 7. 1925.

a remaining oscillation, which is greater than the error of observation and has its origin in the sun itself.

Short-period oscillations.—The difficulties that exist relative to an objective verification of long-period oscillation of the solar radiation are naturally accentuated in the review of changes in the results of measurements from day to day. In the monthly means the short-period oscillations, which are to be referred, at least in part, to instrumental inaccuracies and atmospheric disturbances, are smoothed out, so that in them and still more in the yearly means important changes stand forth more clearly. So long as the short-period oscillations showed such great amplitudes that the percentage errors of determination were considerably exceeded, as was the case in the first years of observation, a decision appears easier. But in the course of time the daily oscillations have become steadily smaller, a circumstance to which F. Linke,¹⁹ W. E. Bernheimer,²⁰ and C. F. Marvin²¹ have called attention. In the main the writers give refinement of the process of observation as the cause. Ac-

TABLE 1.—Relation between the monthly means of the solar constant and the frequency of sun spots

Period	Number of values	Station	Correlation between monthly means and spot frequency
1905 to 1920.....	71	Mount Wilson.....	$r = +0.415 \pm 0.066$
1918 to 1920.....	24	Calama.....	-0.152 ± 0.134
October, 1920, to September, 1922.....	24	Harqua Hala.....	$+0.326 \pm 0.124$
1921.....	12	Montezuma.....	-0.209 ± 0.184

On the question of the reality of these monthly means it is to be remarked that it appears as granted when, as already set forth, we have here before us values that actually represent the amount of the solar energy at given times, and so are completely freed from the influences of the earth's atmosphere.

A representation, after Marvin, of values measured on almost 2,000 days in the years 1902 to 1919 is given in Figure 17. Among other things there are noted the marked

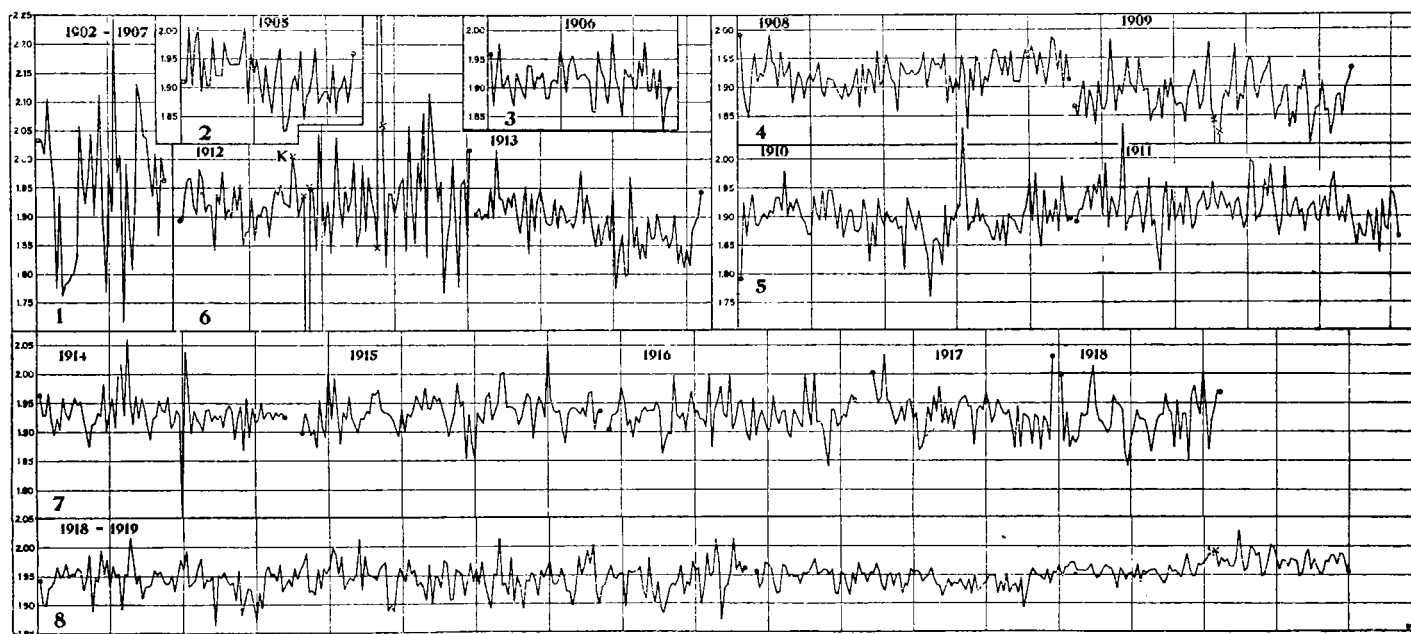


FIGURE 17.—Oscillations of the solar constant from the beginning of observations in 1902 to the end of 1919 (after Marvin)

ording to C. G. Abbot,²² who very recently establishes the continuous decrease in the oscillations, it lies primarily in the fact that the latest stations work under far more favorable conditions.

So far as the monthly means of the solar constant are concerned the available material is considerably greater. As with the yearly means so with the monthly means, it is frequently assumed that a decided change is to be noted with sun-spot frequency and, indeed, in the same direction. This relation, however, seems not to be certain, as appears from an investigation by W. E. Bernheimer.²³ To be sure, there results for the Mount Wilson values the expected positive correlation, but with the new stations it becomes infinitesimally small, and shows, as can be seen in Table 1, in part even an indication of an opposite relation. Additional data are, therefore, still necessary.

oscillation that began in 1912 incidental to the Katma eruption, the persistent decrease in oscillation from year to year, and, especially, the striking diminution in oscillation after the middle of 1919, coincident with the introduction of pyranometric measurements.

The decrease is given statistically in Table 2.

TABLE 2.—Oscillations of the daily values of the solar constant in the different years of observation. The scatter is represented as the probable error in a single day, expressed in percentage of the average value for the whole period, $1.94 \text{ g. cal. cm}^{-2} \text{ min}^{-1}$

Year	Station	Number of days	Amount of scatter
			Per cent
1909.....	Mount Wilson.....	96	1.3
1912.....	Mount Wilson (Katmai).....	100	2.2
1913.....	do.....	80	1.7
1918.....	Mount Wilson.....	56	1.4
1918.....	Calama.....	116	.9
1919.....	Calama, old method.....	131	.9
1919.....	Calama, new method.....	333	.52
January to April, 1922.....	Montezuma.....	452	.49
1922 to 1924.....	Montezuma, Harqua Hala.....	842	.41

¹⁹ *Meteorologische Zeitschrift*. 41. (1924.) p. 74.

²⁰ *Verlag von Julius Springer*. 59. 1921.

²¹ *MONTHLY WEATHER REVIEW*. 53. No. 7. 1925.

²² *Gerlands Beitrage*. 16. (1927.) p. 344.

²³ *Seeltiger-Festschrift*. 1924.

The introduction of pyranometric measurements, a process that is designated as the "Short Method," really indicates an important advance. Hitherto the transmission coefficients have been derived bolographically for different wave lengths only in unlike air masses, that is at different times in the course of a day. The series of objections previously made applies to this. The new process makes it possible to obtain the transparency of the air with a single observation when the brightness of the sky H is measured with a pyranometer in the immediate vicinity of the sun and in addition the water vapor correction ρ/ρ_{sc} is determined, as previously, by the measurement of the band $\rho\sigma\tau$. Then the measure of the prevailing transparency is:

$$F=H\rho_{sc}/\rho$$

After the relation of H to the transmission coefficient has been determined empirically for a rather long series of observations, a single measurement suffices for the determination of the solar constant. The last circumstance is a disadvantage to the method since by it there is established a certain connection with the earlier process.²⁴

A substantially higher degree of accuracy results from these pyranometric measurements. As shown above, there accompanies their introduction a further decrease in daily oscillations, a circumstance that argues against the reality of variability.

As Bernheimer²⁶ has shown from the Montezuma values for 1921 and 1922, the disturbing influences of the earth's atmosphere strangely appear to be not yet fully eliminated even in the pyranometric results. This is confirmed by Marvin's²⁸ investigations of all the data from the same station extending up to 1924. (See fig. 16.) It is to be assumed that the latest, as yet unpublished, results will involve a better extrapolation since Abbot²⁷ has now introduced a new expression for the function F :

$$F=\frac{H\cdot\psi}{P}$$

where P denotes the pyranometric measurement and ψ , the measurement of the area of the so designated water band. If it is then assumed that the influence of the earth's atmosphere is fully eliminated there yet remains the difficulty, raised first by Linke²⁸ and later by Marvin, that the oscillations from day to day (which, in the average of 1,400 individual cases, amount to 0.0117 g. cal. cm.⁻² min.⁻¹, or 0.60 per cent of the mean solar energy per year) just equal the order of the accuracy of the pyranometric measurements.

Nevertheless, short-period oscillation can not, for this reason, be denominated generally as impossible. In line with a remark by Abbot²⁹ it can be said that, although the average departures from the mean of a long series are small, it is still possible that isolated decided departures are not accidental, but real. Simultaneous measurements at two places appear to be especially suited to the examination of such exceptional cases.

Oscillations on the basis of simultaneous measurements at different places.—The relation of simultaneous solar constant measurements was first investigated by Kron,³⁰ who found a correlation:

$$r=+0.508\pm0.071$$

between the results at Mount Wilson and at Bassour, Algeria. For 106 common days in the period 1918–1920 Abbot³¹ finds:

$$r=+0.491\pm0.500$$

Clayton³² and Linke³³ also investigated these data. The latter remarks that the relation appears less pronounced only in 1920. In general it can be said, however, that the results up to 1920 show a remarkably concordant march in the simultaneous values of the solar constant.

It is curious that a striking change in the relation occurs in 1921, when for the first time observations are available for all months from the climatically favored stations at Montezuma and Harqua Hala. For the year 1921 Bernheimer³⁴ finds:

$$r=+0.294\pm0.083$$

It is difficult to give an explanation of this phenomenon unless it is assumed that the observed oscillations of short-period nature are not real because they do not come to light simultaneously at two places. In Figure 18 are reproduced the measurements for 1920 and 1921.

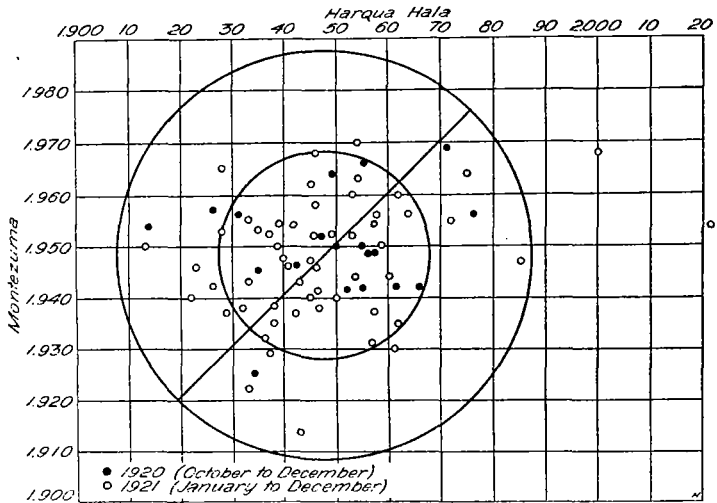


FIGURE 18.—Synchronous values of the solar constant at Montezuma and Harqua Hala (after Bernheimer)

In this the smaller circle include departures up to 1 per cent and the larger circle those up to 2 per cent of the mean value. This material as well as the latest results to November, 1924, inclusive, have been investigated by Marvin³⁵ and, in particular, by Kimball.³⁶ They arrive at the same result reached by Bernheimer in that they demonstrate a further decline of the relation. Thus Kimball finds:

TABLE 3.—Correlations between determinations of the solar constant at Montezuma and Harqua Hala

Period	Num-ber of days	Correlation
October, 1920, to March, 1922.....	99	$r=+0.341\pm0.060$
April, 1922, to July, 1923.....	106	$+0.18\pm0.063$
August, 1923, to November, 1924.....	193	$+0.17\pm0.045$

²⁴ Seeliger-Festschrift. 1924. p. 425 ff.

²⁵ Ibid.

²⁶ MONTHLY WEATHER REVIEW, 53. No. 7. 1925.

²⁷ Gerlands Beiträge, 16. (1927). p. 344.

²⁸ Meteorologische Zeitschrift, 41. (1924.) p. 79.

²⁹ Gerlands Beiträge, 16. (1927.) p. 344.

³⁰ Verlag von Julius Springer. 49. (1914.) p. 68.

³¹ Annals of the Astrophysical Observatory of the Smithsonian Institution. Vol. 14. 1922.

³² World Weather. 1923. p. 218.

³³ Meteorologische Zeitschrift. 41. (1924.) p. 74.

³⁴ Seeliger-Festschrift. 1924. p. 469.

³⁵ MONTHLY WEATHER REVIEW, 53. No. 7. 1925.

³⁶ Ibid.

These results, too, argue very strongly against the reality of short-period oscillations. On the other hand, consideration must be given as follows: Of course, in the dissection of the data alone an oscillation from day to day is investigated, while oscillations of longer period do not come to light. Thus, if the whole period from April, 1922, to November, 1924 (see fig. 13), is considered, there is a certain indication of a relation. When it is considered that in this period solar constant values were obtained on 827 days, of which only 299 were common to both stations, the data are, in the first place, rather scant.

This circumstance, also, renders more difficult the decision as to the reality of the extreme values previously mentioned. In the 827 days a value below 1.900 g. cal. $\text{cm}^{-2} \text{ min}^{-1}$ was measured thirty-six times, but only on 6 of the common days; extreme values above 1.940 g. cal. were measured on 35 days, only 4 of which were common to both stations. No decision as to the reality of extreme values of this kind can be reached along this line to-day. The addition of observations from a third station. Mount Brukkaros in South Africa, will be a matter of importance.

Moreover, consideration must be given to the investigation of the turbidity conditions in the atmosphere, which, as the Katmai years show, often extend over wide areas of the earth. They can influence simultaneous measurements of the solar constant even when they are far from being so powerful as at that time. Dorno,³⁷ in particular, has emphasized this. Widely extended anomalous turbidity phenomena of this kind are not at all rare, as appears from detailed investigations by Kalatin.³⁸ Thus there is shown, for example, an extensive disturbance in the summer of 1919, observed simultaneously at Pavlosk, Russia, and at Davos, Switzerland.

"*Selected Pyrheliometry.*"—In view of the great difficulties, arising from influences of the earth's atmosphere, that beset the solution of the problem of extrapolation to true values of radiation, there arises the question whether, at least for criticism of the oscillations of solar radiation, extrapolation shall be abandoned altogether. Marvin³⁹ was the first to call attention to this. He finds that pyrheliometric observations alone give values almost without error, from which it would be easy to obtain a true solar oscillation, especially when observations are made with instruments equally well adapted and at different, entirely independent points in the driest regions of the earth and at different elevations above sea level. For further increase in accuracy measurements could be made simultaneously at each point with two pyrheliometers.

Abbot gave attention to this and, for the investigation of oscillations in solar radiation, developed a new method called by him "*Selected Pyrheliometry.*"⁴⁰ In this there is an investigation of the results at Mount Wilson from 1910 to 1920; in a second work⁴¹ the investigation was extended to the observations at Montezuma in 1920–1926. The principle of the method can be analyzed as follows: If it is a question of determining only the oscillations of solar radiation and if absolute values are abandoned, then pyrheliometric observations alone would suffice, provided the observations are so made that the disturbing influences of the atmosphere remain the same at each observation.

Abbot chose observation days when the atmosphere had the same transparency and moisture content. Naturally, also, he combined only those observations with the same elevation of the sun, thus having the same air mass. In this way the changes in transparency in the course of the day play no rôle. In the Mount Wilson data the investigation is limited to the month of July in order to increase the trustworthiness of the results. There was then determined the departure of a July value so obtained from the mean value for all months of July and a comparison was made with departures of the earlier solar constant results from their mean value. The outcome of this test is seen in Figure 15. In general there proves to be the march from July to July as it has resulted in solar constant measurements. In particular it is shown that solar constant oscillations are reduced one-half, as has been set forth previously.

Also in the measurements at Montezuma, in so far as they are known, the process of "*Selected Pyrheliometry*" appears to promise success. The results indicate a long-period oscillation of the order of about 2.5 per cent. The difficulty in the employment of the method lies in actually finding a sufficient number of days on which there is a corresponding state of atmospheric conditions. At stations specially favored climatically this (correspondence) will be, indeed, rather the case. To what extent the new method can bring a clarification of the question of the existence of short-period oscillations the future will show. It is welcome that provisional results are no longer published and so at the outset there will be submitted for discussion a complete series of final values.

"*Special oscillations in ultra-violet solar radiation.*"—The results commented upon in the foregoing sections relate throughout to observed oscillations in the total radiation of the sun. A chief difficulty in the decision as to their reality lay in the fact that it was a matter of relatively small amplitude in oscillations, hence the errors of observation were not very much different in order from those oscillations. The problem is forthwith different when observation is made of special oscillations which exceed in considerable measure the order of the error of observation. This, now, appears to be the case with ultra-violet radiation.

After several preliminary investigations in earlier years, in 1925, Abbot⁴² gave his attention in detail to the question as to how far the several spectral regions share in the observed oscillations of total radiation. In the results for 1924 there appears only slight amplitude in changes in total radiation; it is seen almost uniformly in the curve for entire energy; in the short-wave region alone is there indication of marked oscillation. Considerably more striking are the results of investigation of data from 1921 to 1923. As is seen in Figure 13, after high values in 1921 there follows a strong decline in 1922 with minimum to the end of 1924. Abbot arrives at the interesting result that this relatively strong oscillation in the period mentioned comes to light almost not at all in the regions between λ 5,000 and λ 20,000. It is to be ascribed almost exclusively to an oscillation in increasing degree from λ 5,000 to λ 3,500.

This result permits, indeed, a double interpretation: Either the oscillation in the violet and ultra-violet is real and considerably exceeds that in other spectral regions or the oscillations are altogether unworthy of mention and are simulated in the short-wave region by

³⁷ *Meteorologische Zeitschrift*, 36. (1919.) p. 109.

³⁸ *Gerlands Beiträge*, 15. (1926.) p. 376.

³⁹ *MONTHLY WEATHER REVIEW*, 53. No. 7. 1925.

⁴⁰ *MONTHLY WEATHER REVIEW*, 54. (1926.) p. 191.

⁴¹ *Gerlands Beiträge*, 16. (1927.) p. 344.

⁴² *Smithsonian Miscellaneous Collections*, 77. No. 5. (1925.) P. 25.

changes in the transparency of the earth's atmosphere, especially because of ozone bands.

In 1926 E. Pettit⁴³ adduced very valuable new data for the investigation of this phenomenon. His investigations consist in comparisons in intensity of radiation at λ 3,100 and at λ 5,000. The measurement was made with thermopiles, in one case through a silver film, in the other through a gold film with a green celluloid filter in front. Measurements with temporary apparatus in four months of 1924 and a definitive series of observations carried out uninterruptedly after April, 1925, gave a maximum of oscillation of ultra-violet radiation at 83 per cent. This value is reduced to 57 per cent since correction had to be applied on account of the reduced permeability of the filter.⁴⁴ Later observations were made without the celluloid filter.

The data available to March, 1927, have been investigated in detail by Bernheimer.⁴⁵ If the results for 1924 are left out of consideration then observations for two complete years with definitive instrumental equipment show that the highest observed measurement of oscillation amounts to only 26 per cent. In the latest publication⁴⁶ Pettit establishes that the march of the oscillations remains essentially unchanged regardless of whether the values are determined for air mass 1 or extrapolation is made to space outside the atmosphere, that is, for air mass 0. This unexpected circumstance led Bernheimer to investigate whether changes in the earth's atmosphere are not reflected in the oscillation. The monthly means of ultra-violet radiation for the two years have a maximum oscillation of 17 per cent and show, in fact, as appears from Figure 20, a decided seasonal march. If comparison is made with the measurements that were obtained photo-electrically at Arosa⁴⁷ in the same spectral region and with air mass 2.9, there results an agreeing yearly march, which is to be demonstrated in the same manner also in the transmission coefficients for λ 3,200.

G. M. B. Dobson and D. N. Harrison⁴⁸ have recognized a yearly march in the ozone content of the air. Through an investigation Pettit was able to demonstrate that his values for ultra-violet radiation are not materially influenced by the fact that a considerable supposed increase in ozone is assumed from the observed march of the rays. To an increase of 100 per cent in ozone there corresponded a diminution of only 5 per cent in ultra-violet intensity. Pettit comes, therefore, to the conclusion that the strong oscillations observed by him are real and have their origin in the sun.

The strong ozone effect manifests itself principally in a spectral region that lies below that of Pettit. Hence, there can be the opinion that the experiment by Pettit is not conclusive. In reality it appears that the yearly march that occurs in the ultra-violet measurements at Mount Wilson comes out entirely independent of the question of ozone just as (happens) in general turbidity found with total radiation. In Figure 20 this (latter) march is represented in the form of the turbidity factors introduced by Linke.⁴⁹

According to this, high values of ultra-violet radiation occur with clear, winter conditions and low values with much clouded, summer conditions of the atmosphere. In this way there is the temptation to assume that the observed changes in ultra-violet radiation do not take

place in the sun, but reflect processes in the earth's atmosphere. On these grounds it is still premature to enter in detail upon indicated relations of oscillations of ultra-violet radiation to ozone oscillations produced by that radiation and to the march of sun spots and solar constant. This is probably all the more the case since, as previously mentioned, according to the investigations of Marvin the monthly means of the solar constant show

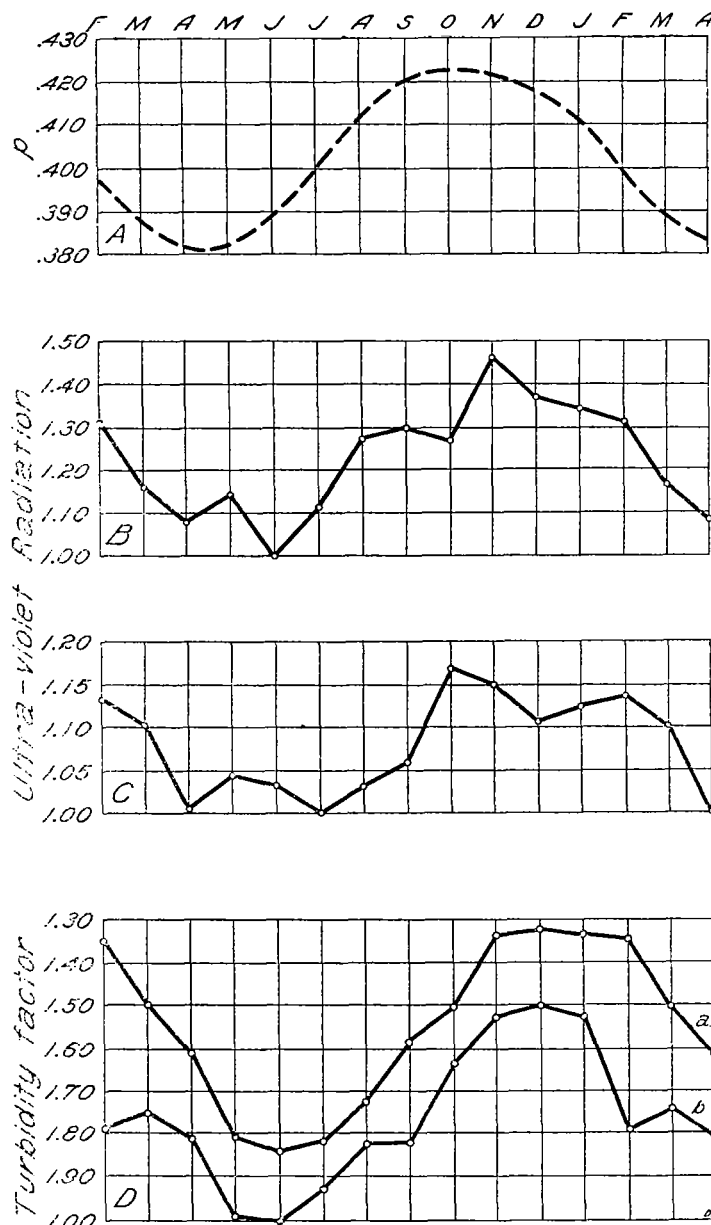


FIGURE 20.—Oscillations of ultra-violet solar radiation compared with turbidity phenomena in the atmosphere of the earth (after Bernheimer)

A. Yearly march of the transmission coefficient for λ 3,200 (Götz). B. Arosa, December, 1921, to July, 1923, ultra-violet radiation of the sun with air mass 2.9. C. Mount Wilson-Tucson, April, 1925, to March, 1927, measurement of the extra-terrestrial ultra-violet radiation (air mass 0). D. Yearly march of the turbidity factor of the atmosphere for (a) Arosa and (b) Upsala.

a dependence on summer and winter conditions of the atmosphere. A decision as to the existence of extra-terrestrial changes in ultra-violet solar radiation could probably be given if the investigations of Pettit were repeated in the Southern Hemisphere. If the oscillations originate in the earth's atmosphere then their march must show a phase shift of six months.—Translated by W. W. Reed.

⁴³ Astronomical Society of the Pacific. Publications. 38. (1926.) P. 21.

⁴⁴ Popular Astronomy. 34. 1926. P. 631.

⁴⁵ Die Naturwissenschaften. 16. (1928.) P. 526.

⁴⁶ National Academy of Sciences. Washington. Proceedings. 13. (1927.) P. 380.

⁴⁷ F. W. Paul Götz. Das Strahlungsklima von Arosa. 1926. Springer. Berlin.

⁴⁸ Proceedings of the Royal Society of London. 110. (1927.) P. 660.

⁴⁹ Astronomische Nachrichten. 221. (1924.) P. 183; Meteorologische Zeitschrift. 41. (1924.) P. 73; Beiträge zur Physik der freien Atmosphäre. 10. 1922.